LIQUID ENVIRONMENTAL STRESS SCREENING

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BIOGRAPHY

John Walker is a mechanical engineer in the Environmental and Electronics Test Branch at the Naval Command, Control and Ocean Surveillance Center, RDT&E Division, in San Diego, CA. After earning a BSME in 1974 from the University of New Haven in West Haven, CT, he worked as a mechanical engineer from 1974 to 1988 at the Naval Surface Warfare Center, White Oak, Silver Spring, MD. He is a member of Pi Tau Sigma and of SAVIAC TAG (Shock and Vibration Information and Analysis Center Technical Advisory Group). He has been at his present position since 1988.

ABSTRACT

This article describes a method of performing Environmental Stress Screening in an inert fluid. Because the liquid has a high dielectric strength, the items being screened can be energized and operational while submerged. Transmitting vibrations through the liquid to the item being screened permits screening without the use of fixtures, and the liquid's high heat capacity allows very rapid temperature changes, either by pumping hot or cold liquid from remote reservoirs or by moving the device from a hot tank to a cold tank. A prototype screening system has been built at Naval Command, Control and Ocean Surveillance Center, RDT&E Division (NRaD), and faults induced in a small (47 pieces) lot of printed wiring boards have been detected.

environmental stress screening
fixtureless
vibration
thermal cycling
perfluorinated fluids

INTRODUCTION

Environmental Stress Screening (ESS) consists of subjecting newly produced items to thermal cycling and random vibration and other environmental stresses in order to force latent defects to surface. Such things as cold solder joints and cracks in traces on printed wiring boards (PWBs), which may not cause problems during bench testing, are forced to fail during ESS rather than be placed into service only to fail at a later time. Failures in service can be both expensive to repair and dangerous, especially in the case of equipment which is vital to the functioning of a ship or aircraft. For maximum effectiveness, the ESS process must be tailored for each specific item that is to be screened. Forcing the process to conform to an arbitrary standard, either in the vibration spectrum or the temperature limits and times for thermal cycling, is generally counterproductive. The ESS process is applied to production items that have been qualified through environmental testing to survive the environments they will encounter while in service. ESS is meant to detect defects caused by workmanship errors, not to qualify a design.

TYPICAL PROBLEMS OF ESS

A recurring expensive and time-consuming problem encountered in vibration testing is the need to design and fabricate fixtures for various test items. For vibration tests, the fixture must duplicate as closely as possible the mounting configuration the test item will encounter during service. This is not the case for vibration screens used in ESS, since the purpose is not to simulate the service environment but to detect defects in the item. Recognition of this fact permits great freedom in the design of fixtures to be used for vibration screening or even the possibility of eliminating fixtures completely.

Thermal cycling, another major factor of ESS, is usually carried out in an environmental chamber using air as the heat-transfer medium. The rate of heat transfer to and from the item being screened and, thus, the rate of temperature change of the item, is limited by the thermal conductivity of the air. The rate of temperature change of the item under test has a large influence on the effectiveness of the screen, with a higher rate providing more effective screening. Paragraph 4.1 of NAVMAT P-9492 states "The rate of change of internal parts should fall within 1°F and 40°F per minute. The higher rates provide the best screening."*

* NAVMAT P-9492, "Navy Manufacturing Screening Program," Department of the Navy, May 1979.

PROJECTED IMPROVEMENTS

Accelerated aging, or "burn-in" screening, of electronics consists of operating an item at higher than normal operating temperature for a short period of time. The higher temperature forces infant mortality failures to appear sooner than they would at normal temperature. Burn-in screens performed in air have some drawbacks, including uneven heating throughout the device which leads to the development of hot spots. One method of burn-in screening that avoids these difficulties is that of immersing the items to be screened in a bath of inert fluorocarbon liquid during the burn-in. Commercial burn-in systems using fluorocarbon-liquid immersion are available from several manufacturers.

The fluorocarbon liquid is available from 3M under the trade name Fluorinert® and from several other companies under various trade names. A variety of liquids are available with different pour points and boiling points, with the former ranging from -110°C to +33°C and the latter from +56°C to +253°C. Because these liquids have a very high dielectric strength, electronic equipment can be energized and operated normally while immersed. The liquids exhibit minimal solvent action; thus, adhesives and labels are not affected by the immersion. These liquids are perfluorinated (i.e., all of the hydrogen atoms have been replaced by fluorine atoms), and the lack of chlorine means that they pose no known threat to the earth's ozone layer. The liquids are also nontoxic and nonflammable, so that no extraordinary precautions are required during handling, storage, or use. The only apparent drawback is cost, but since the liquid is not consumed it is properly considered a capital cost item.

Using these liquids permits higher temperatures to be used during burn-in since hot spots are eliminated and heat can be carried away from the PWB at very high rates (heat-transfer coefficients for Fluorinert® are approximately 30 times that for air).** The higher temperatures permit shorter screen times to achieve equal results. This idea can be applied to thermal cycling as well. Advantages of performing thermal cycling in liquid rather than air include the ability to change temperature more rapidly, faster stabilization at the new temperature, and more uniform temperature distribution across the surface of the item being screened. Complexity of equipment can also be greatly reduced, since the item can simply be moved from one container at a low temperature to another at a high temperature as many times as required.

The possibility of eliminating fixtures for vibration screening has been mentioned above. The problem then becomes one of inducing vibration in the test item without a direct mechanical connection between the item and a vibration source. Immersing the test item in a liquid greatly simplifies this problem, since the density and relative incompressibility of a liquid compared to air facilitate the transfer of vibrations. Inexpensive ultrasonic cleaners use this idea as their basic operating principle.

An obvious means of minimizing the total time required for vibration and thermal screening is to combine the two procedures, if the equipment has such a capability.*

SCREENING SYSTEM

To test the feasibility of performing ESS in a liquid, an experimental screening system was assembled in the Naval Command, Control and Ocean Surveillance Center, RDT&E Division (NRaD) environmental test area. This system was composed of three pieces: an electrodynamic shaker, a test chamber, and a control system. The test chamber originally consisted of an open top Plexiglas® tank with one end replaced by a rubber diaphragm with a rectangular metal plate in the middle. The plate had a nut welded to its outside face and a piece of threaded rod screwed into the nut. The other end of the threaded rod was connected to the shaker. The threaded rod was eventually removed and another plate was designed and fabricated which would permit the direct attachment of the diaphragm plate to the shaker head. The shaker and test chamber were set up with a Time/Data random vibration controller built around a Digital Equipment Corporation PDP-11/34. Figure 1 is an overall view of the original setup. The tank is at the far left, the controller at the far right, and the power amplifier is between them.

INITIAL TUNING

The success of the liquid ESS (LESS) system requires that vibrations be transmitted to PWBs through a liquid, without a rigid connection to a shaker or whatever vibration source is ultimately selected. This is a major advantage of the system:

* NAVMAT P-9492, "Navy Manufacturing Screening Program," Department of the Navy, May 1979.

** 3M Industrial Chemical Products Division, "Fluorinert Electronic Liquids Product Manual," 1988.

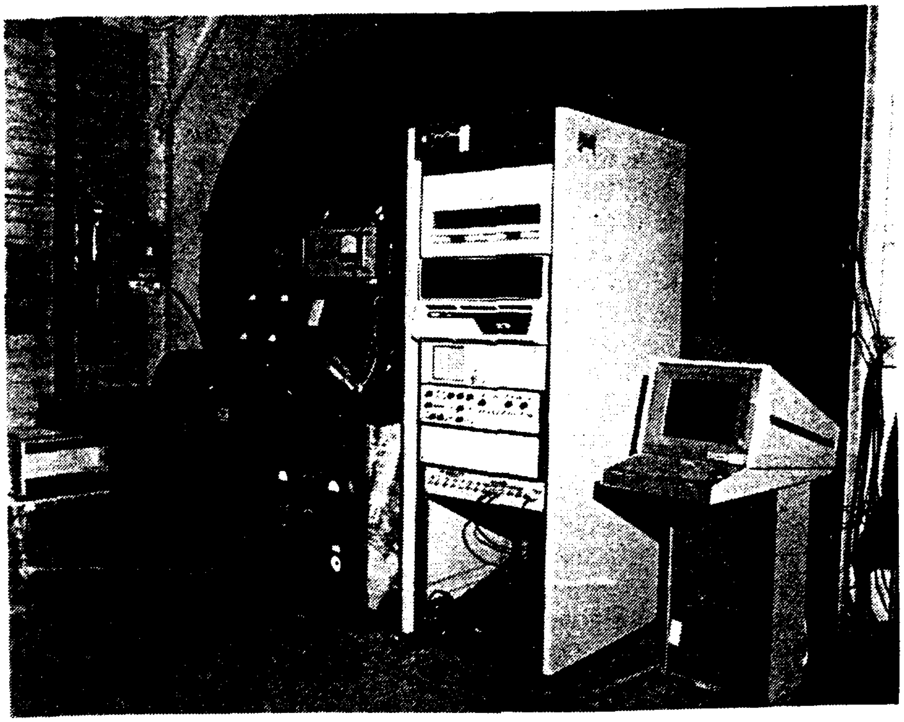

Figure 1. Overall view of original test setup.

that it does not require custom fixturing for each new PWB. With this in mind, tests were performed with the test system to demonstrate that liquid would provide a sufficiently rigid connection to allow a particular spectrum to be transmitted consistently to a PWB in the liquid. The control accelerometer was placed on a PWB. The PWB was hung in the test tank by two strings arranged to hold it parallel to the rubber diaphragm in the end of the tank. The tank was filled with distilled water for preliminary testing. The control system was then powered up and observed as it operated. The control system was able to control the spectrum after the low-frequency end had been modified to avoid the problem of water sloshing out of the tank.

ACCELEROMETER AND SIGNAL CONDITIONER

The accelerometer chosen to control the random vibration was an Endevco Model 22 Picomin. This microminiature accelerometer weighs only 140 mg and it is normally mounted with adhesive. Its small mass allows it to be used on small test items without significantly altering their mass. The accelerometer is a piezoelectric device, producing output in pC/g. The Time/Data controller, like most vibration controllers, expects a voltage proportional to acceleration as its input, so the charge output of the accelerometer must be converted to voltage. This is done by using an MB Dynamics "Zero Drive" N400 voltage amplifier with a line driver between the amplifier and the accelerometer. The line driver is powered by a −20 VDC supplied by the N400 over the same coaxial cable that carries the acceleration signal.

Piezoelectric accelerometers produce an output when they are subjected to acceleration or are in the presence of acoustic energy. The acoustic energy induces vibrations of the crystal element. This is not usually a problem, since the part of the signal due to acceleration overwhelms the part of the signal caused by acoustic excitation, but when the accelerometer is submerged as it is here, difficulties can occur. An output can be produced in the presence of acoustic energy even if the accelerometer is mounted on an unmoving surface. This is clearly undesirable. To avoid this problem, a waterproof housing was designed and fabricated for the accelerometer. It consisted of an aluminum barrel, closed at one end and threaded for a brass plug at the other. The accelerometer was glued to the inside bottom of the barrel with its cable routed through a

slot in the barrel's side. The brass plug was then installed and the plug and slot were sealed with room temperature vulcanizing silicone. This arrangement allowed the accelerometer to be surrounded by air while the housing was submerged, thus ensuring that it responded only to acceleration. In use, the housing was attached to the PWB with double-sided tape which made it easy to change the accelerometer from one PWB to the next. Figure 2 shows the accelerometer housing in place on a PWB ready for use.

CLOSED-LOOP CONTROL

When random vibration is performed, a closed loop control system is used to control the power amplifier that drives the shaker. This control system is centered around a minicomputer with analog-to-digital (A/D) and digital-to-analog (D/A) converters. The power amplifier is controlled through the D/A converter. The control accelerometer is mounted on a surface where the random spectrum is required, usually on the shaker table. The desired random spectrum is converted to a time domain signal and sent to the power amplifier, which in turn, causes the shaker to vibrate. The control accelerometer responds to the resulting vibration. The output of the accelerometer is sent to the A/D converter where it is digitized. The data are transformed to the frequency domain and compared with the desired spectrum. The drive spectrum is then modified in such a way as to cause the response of the control accelerometer to more closely match the desired spectrum, and the new spectrum is transformed back to the time domain and sent to the power amplifier through the D/A converter. This process continuously updates the output signal to the power amplifier, keeping the spectrum within the specified tolerance.

The closed loop control system just described ordinarily requires a rigid connection between the shaker head and the control accelerometer. If the characteristics of the connection are unstable, the computer cannot keep the spectrum shape within tolerance.

The original Time/Data system quit functioning and because of its age, service was no longer available. Thus, a new controller was necessary. Fortunately, NRaD's Environmental and Electronic Test Branch had recently acquired an Unholtz-Dickie Model 400AT random controller. Unfortunately, the controller quit functioning shortly after the substitution was made and the warranty had expired. Funds

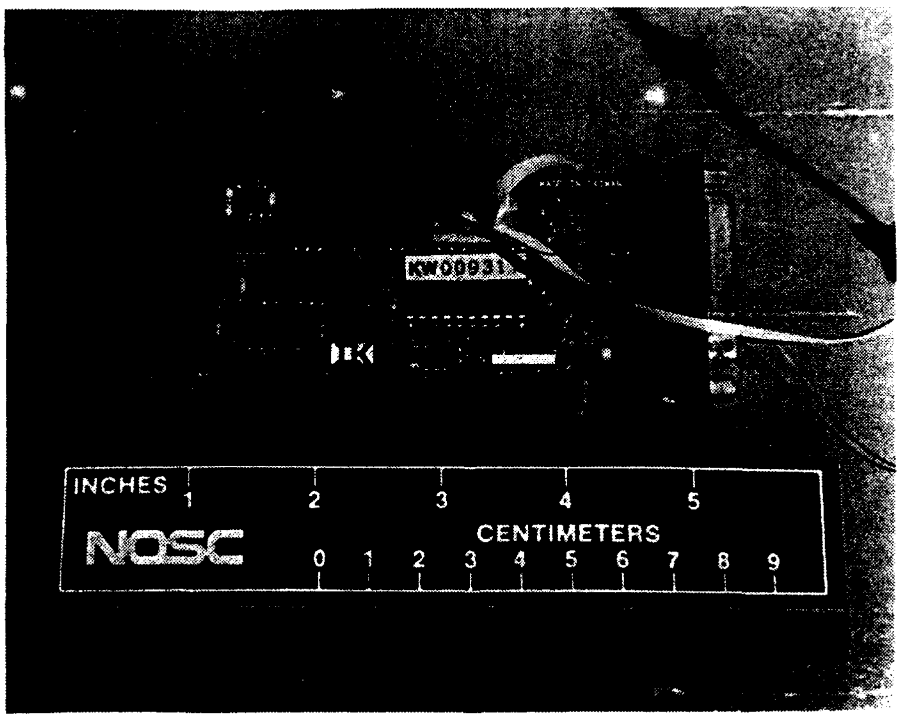

Figure 2. Accelerometer housing on PWB.

were immediately made available to pay for the repair and, after some months had passed, the purchase order was placed with the company to do the repair. Once the company received the purchase order, the repair took only about a week, including shipping to and from Connecticut. The Unholtz-Dickie controller is presently controlling the LESS system.

THERMAL CAPABILITY

Thermal-cycling capability was added to the system by setting up two small temperature chambers nearby, each with a stainless-steel pan inside. One chamber was programmed for a constant temperature of +160°F and the other for a constant 0°F. The pans were filled with Fluorinert® FC-43 and the necessary plumbing was installed to enable the liquid to be pumped in and out of the Plexiglas® tank, as desired. Thus, the temperature could be changed during vibration by pumping the liquid in and out, resulting in combining random vibration and thermal cycling into one procedure. It proved to be impossible to pump liquid in and out under manual control without causing the computer to abort vibration, because the liquid level in the tank changed. This caused the transfer characteristics of the system to change faster than the computer could update the drive spectrum. An automatic control system could probably be designed to allow changing the liquid during vibration should that prove to be desirable. Perhaps closed-loop control of vibration is not necessary for effective screening and the liquid could then be changed at will without interfering with the vibration.

Using temperature chambers for storage of hot and cold liquid was not practical. The time required for the liquid to reach equilibrium temperature with the chamber was excessive, since the heat had to transfer to or from the air in each chamber. Surprisingly large evaporation losses occurred in the liquid in the pan. A new arrangement was put together with two cylindrical stainless-steel tanks, one with an immersion heater and the other with an immersion cooler probe. These two tanks were filled with liquid and placed in a large insulated thermal cart to minimize heat flow to and from the surroundings. Figure 3 shows the tanks in place.

The original idea of pumping hot and cold liquid from the offline reservoirs into the test chambers during vibration testing proved impractical. There were problems pumping liquid in and out of the test chamber even with the vibration off. The

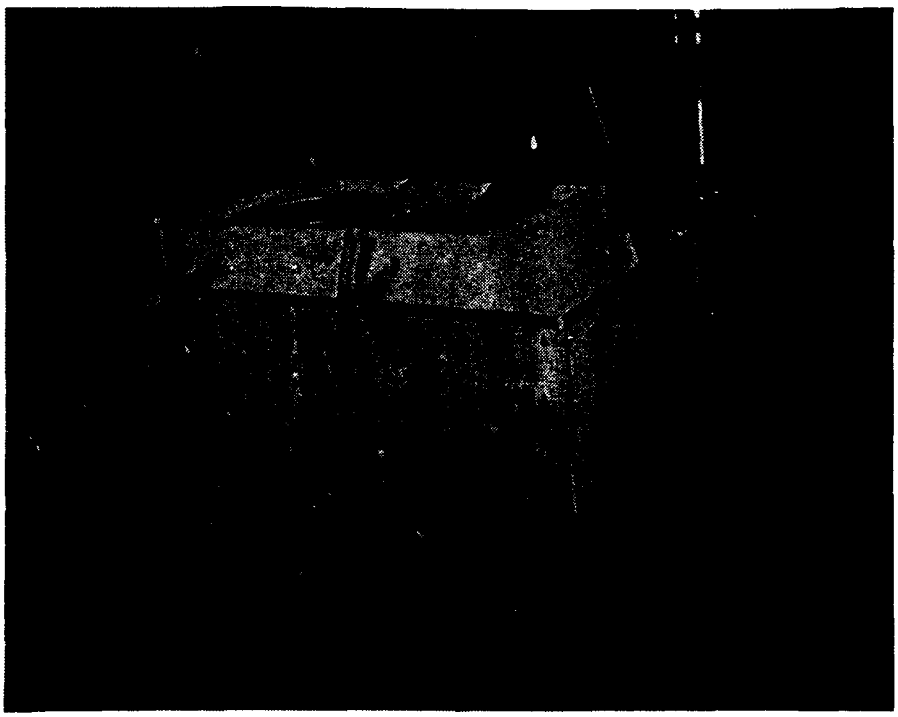

Figure 3. Thermal cart.

biggest problem was that the mixing of hot and cold liquid caused reservoir temperatures to move toward ambient temperature. This problem was alleviated by changing the procedure so that instead of moving the liquid we moved the PWB. The PWB was simply dunked in one tank and then the other. This maximized the temperature rate of change of the PWB and minimized the temperature changes in the tanks. Hollow polypropylene balls floating on the liquid served to minimize evaporation losses without interfering with the dunking process.

SCREEN ITEMS

Demonstrating the use of a screening system can most directly be done by using it to screen a sample of PWBs with known workmanship defects. The first boards used to set up this system were bare boards containing no components. They were followed by a set of 10 portable AM pocket radios, which were followed in turn by a set of 47 printer interface boards meant for use with IBM compatible personal computers. The printer interface boards were Kouwell Model KW-507B parallel printer interfaces.

SPECTRUM SHAPING

The bare boards were used to do the initial spectrum shaping that was necessary to prevent liquid losses due to sloshing. They could be immersed in distilled water without risk of damage and, thus, could be used to demonstrate the feasibility of transmitting vibrations through a liquid in a controllable manner. Using distilled water in place of Fluorinert® was done for the following two reasons: (1) because of lag time in the government purchasing process, no Fluorinert® was yet available when the preliminary work was begun, and (2) early attempts at controlling the spectrum sometimes failed in such a manner that the contents of the test tank wound up on the floor. Distilled water was much less expensive to replace when these mishaps occurred. The first arrangement chosen to show the feasibility of coupling vibrations through the water is shown in figure 4. The Plexiglas® tank was partially filled with distilled water and the circuit card was suspended so as to be partially submerged with the accelerometer mounted on the card above the waterline. This arrangement ensured that the accelerometer was responding only to vibrations of the board. The spectrum recommended as a starting point in NAVMAT P-9492* was programmed into the controller and the shaker was started. While the controller was able to maintain the spectrum for short time, water would slosh over the sides of the tank and the test would eventually be aborted. Experimentation determined that reducing the low frequency content of the spectrum would avoid this problem, so the spectrum was changed. Table 1 lists the spectrum used. Figure 5 is a plot of the spectrum.

Table 1. Vibration spectrum.

Frequency (Hz)	Level(G**2/Hz)
20	0.001
80	0.04
340	0.04
2000	0.0068

AM RADIOS

After the spectrum had been shaped using the bare boards, and the Fluorinert® had arrived, AM radios were used as test subjects. The radios were prepared by removing them from their cases. They consisted of a single circuit board, a speaker, and a battery holder. A jack on the board made it possible to plug in a supplied earphone. The speakers were removed and an extension cable was made up so that the battery could be several feet from the board during testing. The boards were so small that finding a flat spot to mount the accelerometer was difficult. With the accelerometer in place, the first sample was tuned to a strong station with the idea that a failure during vibration would be easily detected merely by listening with the earphone. In practice, this proved impractical. First of all, a shift in the tuning occurred when the radio was immersed in the Fluorinert®, probably caused by the liquid changing the characteristics of the tuning capacitor. This was easily overcome by setting the tuning with the radio immersed. The next difficulty encountered was hearing the radio over the noise of the shaker. The air-cooled shaker was very noisy and was placed next to the tank. Earmuff-type hearing protectors worn over the earphone were marginally successful, but the volume of the radio still had to be set to an uncomfortably high level. Also, because an AM radio is subject to electrical interference, it was impossible to tell whether noise in the audio was due to the vibration causing defects to surface or to interference from other laboratory equipment. Had the audio output ceased completely, it would have been simple to determine but intermittent dropouts could not be reliably detected.

* NAVMAT P-9492, "Navy Manufacturing Screening Program," Department of the Navy, May 1979.

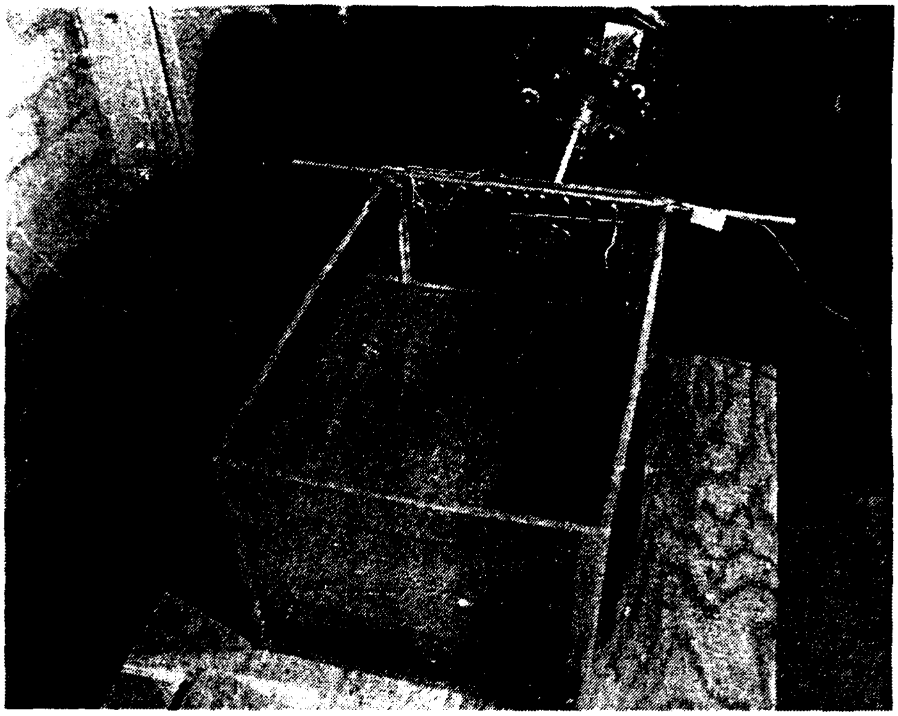

Figure 4. Preliminary vibration setup.

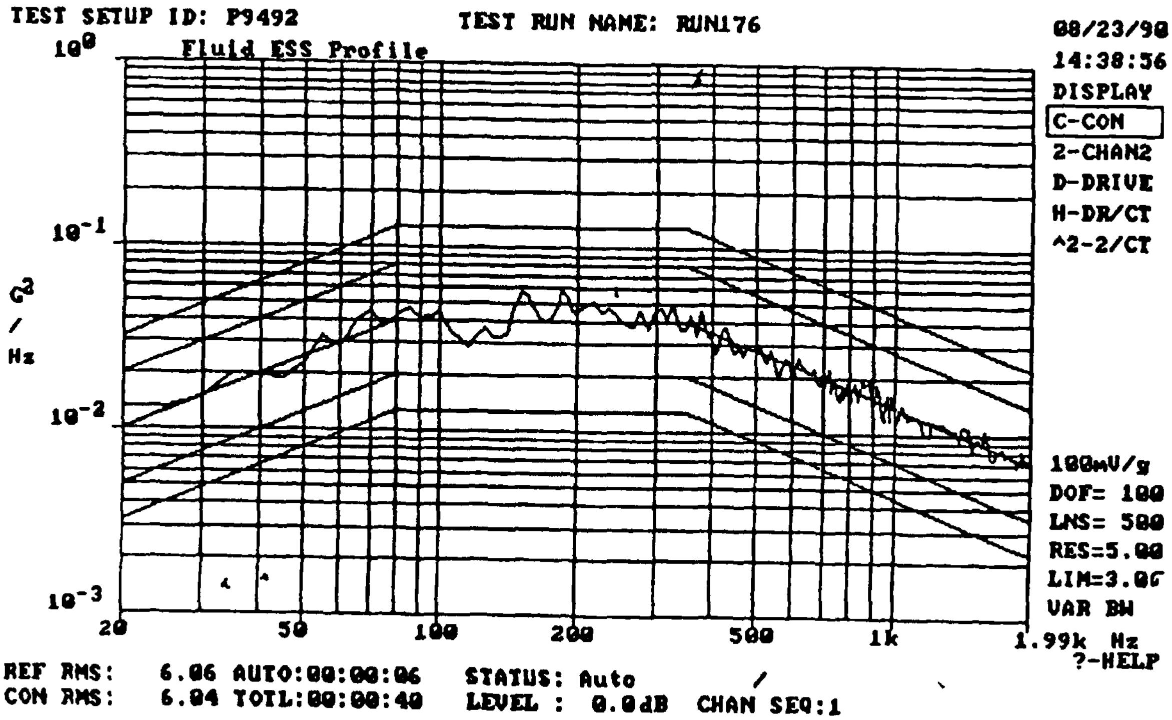

Figure 5. Vibration spectrum.

Another problem was the reliability of these radios. At the price we paid (about $4 each), we had hoped a few would be flawed but they all worked. It was therefore necessary to induce flaws in some of the radios. This was done by removing most of the solder from one lead of a capacitor, leaving just enough to make electrical contact while providing almost no mechanical strength. After this modification was made, the radios would function, but could be made to cut out by manipulating the desoldered lead. This is a type of flaw that ESS is meant to detect. Results of vibrating the flawed radios were inconclusive, primarily because the high-ambient-noise level prevented accurate monitoring.

PRINTER INTERFACES

The printer interface boards were screened next. A monitoring system was assembled so that the boards could be operated during vibration and errors would be detected. The monitoring system consisted of an IBM PC with a ribbon-cable extender in one of the expansion slots. The ribbon cable had a card edge connector on the outboard end into which the printer interface plugged. The output of the interface, which normally goes to a printer, was fed back in to the computer through an IEEE-488 interface in another expansion slot. A program was written that sent out characters to the printer interface and read characters back in through the IEEE-488 interface. Any differences in the character streams were errors and were flagged on the screen. The printer-interface card hung in the test tank parallel to the shaker head. The accelerometer was mounted on an IC on the card with double-faced tape. Figure 6 shows the test tank with an interface board in place. The monitoring PC is on the left. Figure 7 is a view looking down between the board and the shaker head.

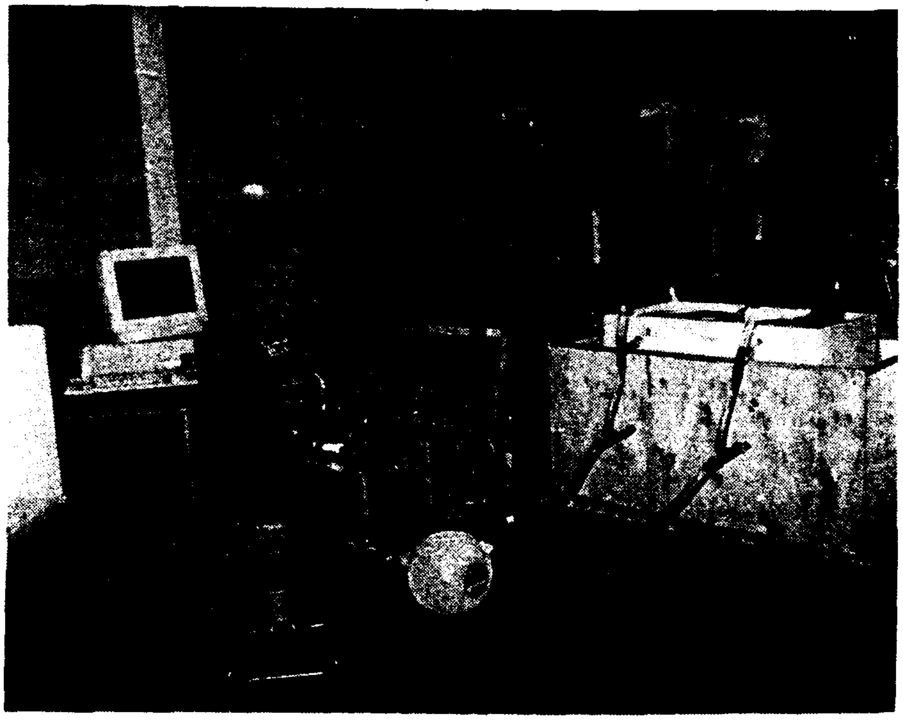

Figure 6. Test tank with interface board and monitoring PC.

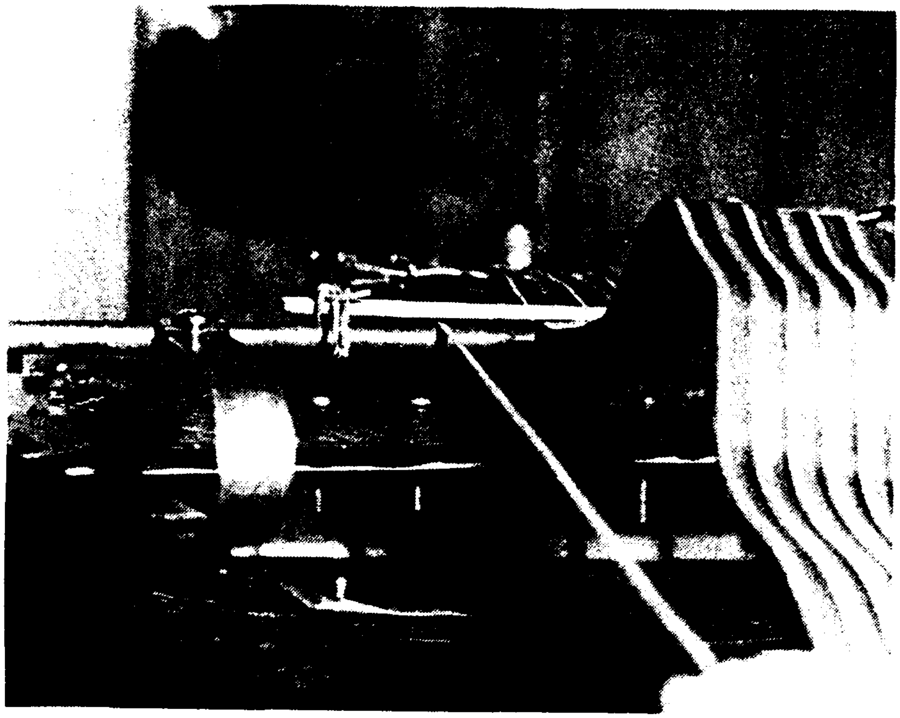

Figure 7. Looking down between board and shaker head.

The printer interfaces purchased for this program were screened for defects as they were received. None were found. This meant that either there were no defects or the process used to search for defects was flawed. As the interfaces all functioned properly before, during, and after screening and no flaws were apparent under visual inspection we assumed them to be defect free. To test the screening system, defects were intentionally introduced on the interface boards.

Defects were introduced on the printer-interface boards by desoldering some of the leads on the board and resoldering them with a soldering iron barely warm enough to melt the solder. The resulting solder joints were mechanically weak and electrically unpredictable. The solder altered joints were on the 25-pin connector through which the output signal passes. Three boards, serial nos. 9317, 9333, and 9338, had their joints resoldered. The remainder were left alone. The altered joints are shown in figure 8.

The three modified boards were put through the screen. Figure 9 shows one of the boards during vibration. Serial no. 9317 functioned properly before the vibration was started, but exhibited errors during vibration. It functioned normally again after the vibration was stopped. Serial number 9338 functioned normally before vibration but began exhibiting errors during vibration and continued to exhibit errors after the vibration stopped. Serial no. 9333 functioned normally before, during, and after vibration, but exhibited errors during and after temperature screening. The remaining 44 interface boards were put through the same process, but no errors were observed. The three defective boards were detected during the screening and the others were apparently unaffected. The process uncovered an intermittent error in one case. Normally, intermittent errors are the most difficult type of errors to troubleshoot, and screening them out before they get into a final assembly is highly desirable. The fact that two of the defects showed up under vibration and one during temperature cycling shows that both procedures are necessary for an effective screen.

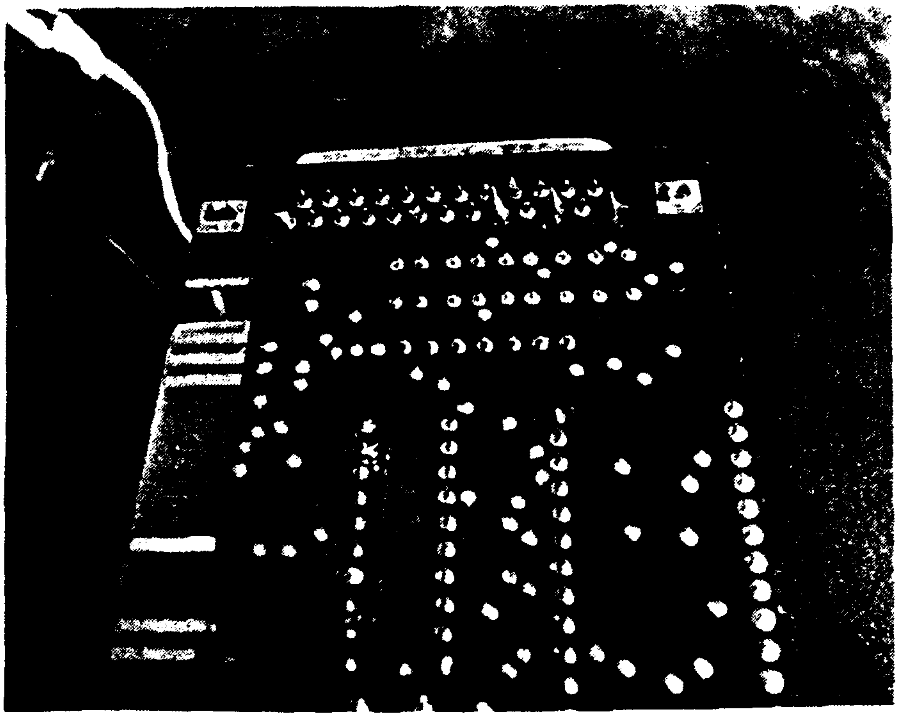

Figure 8. Printer-interface board with induced flaws.

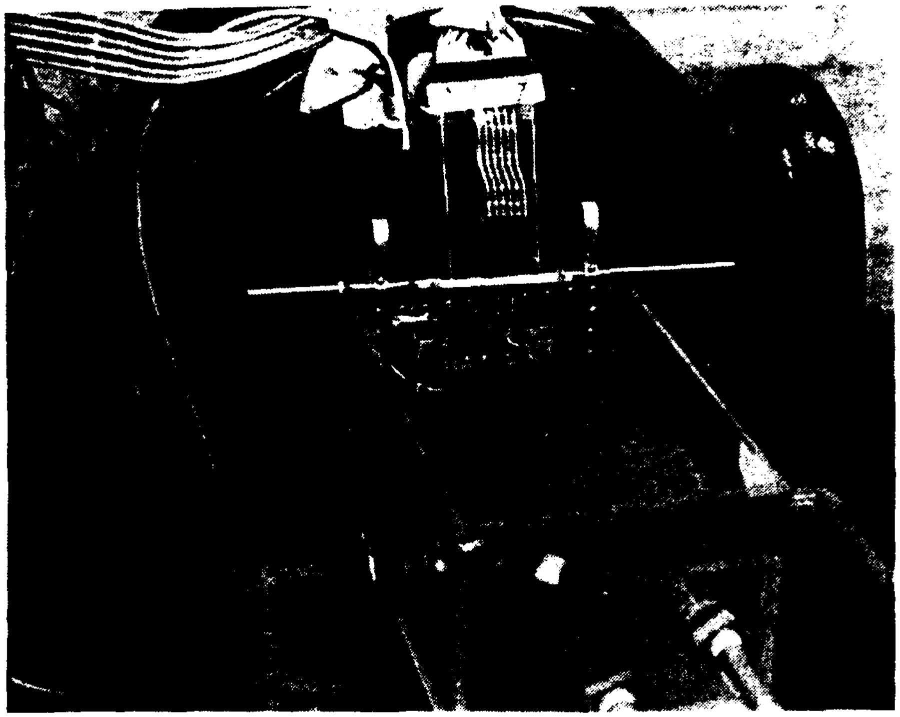

Figure 9. Board undergoing vibration.

CONCLUSIONS AND RECOMMENDATIONS

Subjecting newly produced electronic devices to Environmental Stress Screening in an inert liquid is both practical and cost effective.

Further investigation of several aspects of the LESS process is necessary if this is to become a viable commercial process The first avenue that bears exploration is that of running the vibration system open loop without the necessity of mounting an accelerometer on each board as it goes through the vibration process. If the system can be run reliably, it will open up the possibility of screening several boards at once, and eliminate the necessity of shutting down the vibration and remounting the control accelerometer on each new board. This also will permit the liquid to be changed during vibration so that thermal screening can take place simultaneously. The development of a capability to screen several boards simultaneously is another desirable goal. Thermal screening of more than one board does not appear to pose any problem, but vibrating several boards at once will require a substantial development effort.

To create more confidence in the LESS process a larger set of boards should be screened. An immediate difficulty is finding a method of monitoring the performance of the items being screened. This requirement often necessitates the fabrication of a test set if the item being screened is a single board or a subassembly of several boards. Involving one or more manufacturers of PWBs may alleviate this problem if an arrangement could be made with the manufacturer to supply both a large sample of items requiring screening and a means of monitoring their performance. Involving the manufacturing community can be a way of publicizing the LESS process in order to accelerate the process of development.

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